Higgs Boson Searches at LEP Up To $\sqrt{s} = 202$ GeV

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Abstract

The latest preliminary combined results of the Higgs boson searches from the LEP experiments ALEPH, DELPHI, L3 and OPAL are presented. A general scan of the MSSM parameters is performed and leads to stringent lower mass limits and for the first time excludes low $\tan\beta$ values.

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1 Standard Model Higgs Boson

The search for Higgs bosons at LEP shows no indication of a signal. This review includes the data from the outstanding performance of the LEP accelerator in 1999 with a collected luminosity of about 900 pb^{-1} at $\sqrt{s} = 192$ to 202 GeV[1]. The confidence levels CL_b for a signal observation and CL_s for setting mass limits are shown in Fig. 1. The resulting Standard Model (SM) Higgs boson mass limit is 107.9 GeV/c^2 at 95% CL. The reconstructed mass distribution is shown in Fig. 2. In extensions of the SM the HZZ coupling might be weaker and thus the production cross section is reduced. Figure 2 shows limits on the reduction factor at 95% CL. Even if the SM cross section is reduced by a factor three, a Higgs boson mass up to 103 GeV/c^2 is excluded.
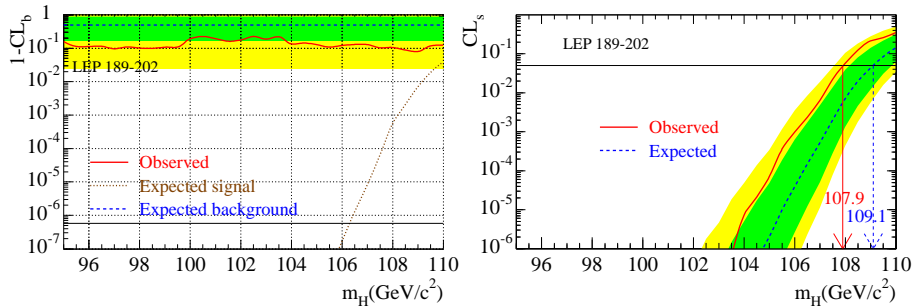

Figure 1: Confidence levels CL_b and CL_s from combining the data collected by the four LEP experiments at energies from 189 to 202 GeV. The solid curve is the observed result and the dashed curve the expected median. The shaded areas represent the symmetric 1σ and 2σ probability bands. The horizontal line at $1 - CL_b = 5.7 \times 10^{-7}$ indicates the level for a 5σ discovery, which shows that a 106 GeV/c^2 Higgs boson could have been discovered, and the intersections of the curves with the horizontal line at $CL_s = 0.05$ give the mass limits at 95% CL.
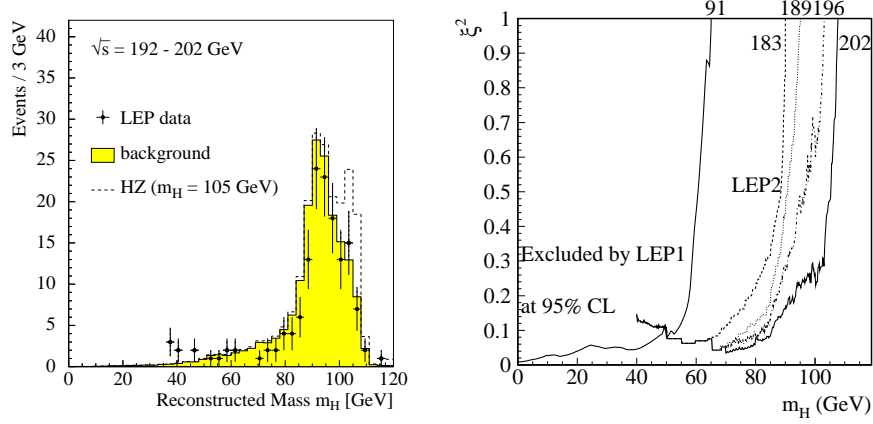
Figure 2: Left: Distribution of the reconstructed SM Higgs boson mass in searches conducted at energies between 192 and 202 GeV. The figure displays the data (dots with error bars), the predicted SM background (shaded histogram) and the prediction for a Higgs boson of 105 GeV/c^2 mass (dashed histogram). The number of data events selected for this figure is 148, while 175 are expected from SM background processes. A signal at 105 GeV/c^2 mass would contribute with 36 events. Right: The 95% CL upper bound on ξ^2 as a function of m_H, where $\xi = g_{HZZ}/g_{HZZ}^{SM}$ is the HZZ coupling relative to the SM coupling, including combined LEP1 [2] and LEP2 [1] results. The excluded regions are shown for data including up to 91, 183, 189, 196, and 202 GeV center-of-mass energies.

2   MSSM Benchmark Results

The Minimal Supersymmetric extension of the Standard Model (MSSM) is the most attractive extension of the SM. The LEP experiments have searched for the reactions $e^+e^- \rightarrow hA \rightarrow b\bar{b}b\bar{b}$ and $b\bar{b}\tau^+\tau^-$. No indication of a signal has been observed as shown in Fig. 3 for the example of $m_h \approx m_A$, and the resulting confidence levels CL_b and CL_s are given. Figure 4 shows the so-called benchmark results in the MSSM for large mixing in the scalar top sector (m_h-max) for CL_b and CL_s, leading to mass limits of 88.3 and 88.4 GeV/c^2 on the CP-even and CP-odd neutral Higgs bosons, and to an exclusion of the range $0.7 < \tan\beta < 1.8$ at 95% CL [1].
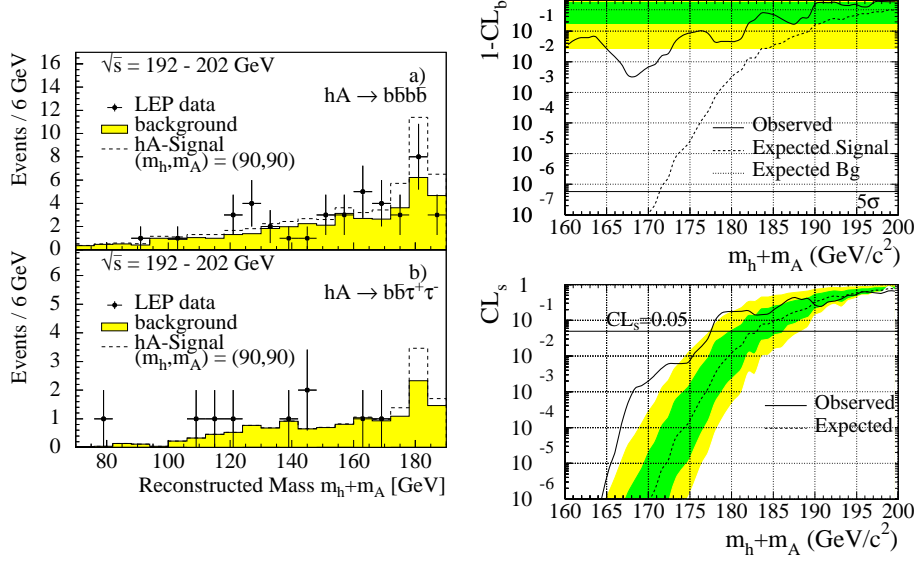
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Figure 3: Left: Distribution of the reconstructed Higgs mass sum $m_h + m_A$ in searches for the MSSM process $e^+e^- \to hA \to b\bar{b}b\bar{b}$ and $b\bar{b}\tau^+\tau^-$. The data of the four LEP experiments collected at energies from 192 to 202 GeV are added. The figure displays the data (dots with error bars), the predicted SM background (shaded histogram) and the prediction for a MSSM signal with $m_h \approx m_A = 90$ GeV/c^2 (dashed histogram) for which the maximal cross-section $(\cos^2(\beta - \alpha) = 1)$ has been assumed. In the $hA \to b\bar{b}b\bar{b}$ case the mass sum $m_h + m_A$ is shown only for the dijet pair with the smallest mass difference $|m_h - m_A|$. The number of data events entering the upper (lower) figure is 42 (9) for 39.5 (11.2) SM background events expected. A signal with the above characteristics would produce 14.7 (0.8) events. Right: The confidence level CL_b and CL_s as a function of $m_h + m_A$, for the m_h-max benchmark and the particular case $m_h \approx m_A$ (where only the $e^+e^- \to hA$ process contributes since $\sin^2(\beta - \alpha) \approx 0$). The straight dotted line at 50% and the shaded bands represent the median result and the symmetric 1σ and 2σ probability bands. The solid curve is the observed result and the dashed curve shows the expected median. The horizontal line at $1 - CL_b = 5.7 \times 10^{-7}$ indicates the level for a 5σ discovery and the intersections of the curves with the horizontal line at $CL_s = 0.05$ give the limit on $m_h + m_A$ at 95% CL.
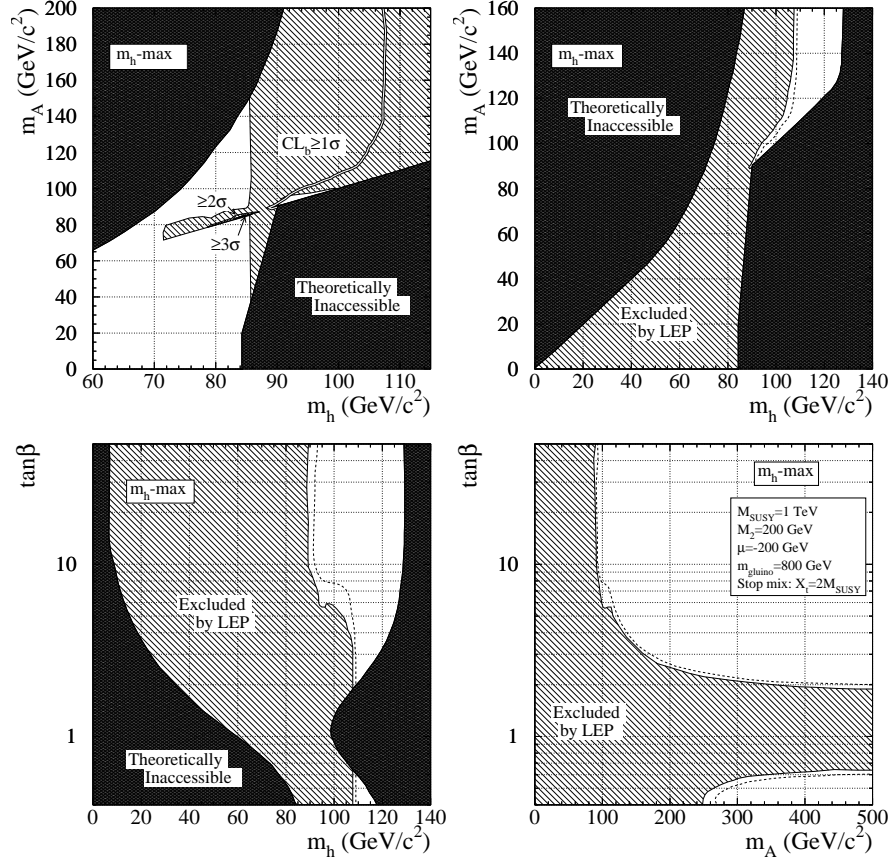
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Figure 4: Upper left: Distribution of the discovery confidence level $1 - CL_b$ for the m_h-max benchmark, projected onto the (m_h, m_A) plane from combining the data of the four LEP experiments at energies from 192 to 202 GeV. In the white domain the observation either shows a deficit or is less than 1σ above the background prediction; in the domains labelled 1σ, 2σ and 3σ the observation is between 1 and 2σ, 2 and 3σ and larger than 3σ, respectively, of the prediction. The other plots show the 95% CL bounds on m_h, m_A and $\tan\beta$ for the m_h-max benchmark. The full lines represent the actual observation and the dashed lines the limits expected on the basis of 'background only' Monte Carlo experiments. Upper right: projection (m_h, m_A); lower left: projection $(m_h, \tan\beta)$; lower right: projection $(m_A, \tan\beta)$.

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3 A General MSSM Parameter Scan

Important reductions of the mass limits compared with benchmark results were reported for LEP1 and LEP2 data[3]. With increasing statistics the reduction was only 6 to 8 GeV/c^2 including the 189 GeV data of one LEP experiment (DELPHI)[4] and similar for OPAL[5]. Figure 4 shows new results from a MSSM parameter scan including the combined LEP data up to 202 GeV for CL_b and CL_s, leading to mass limits of 86 and 87 GeV/c^2 on the CP-even and CP-odd neutral Higgs bosons, and an exclusion of the range $0.7 < \tan\beta < 1.8$ at 95% CL. These limits are almost identical to the benchmark limits (Fig. 4), which is expected for the high luminosity of the combined data.
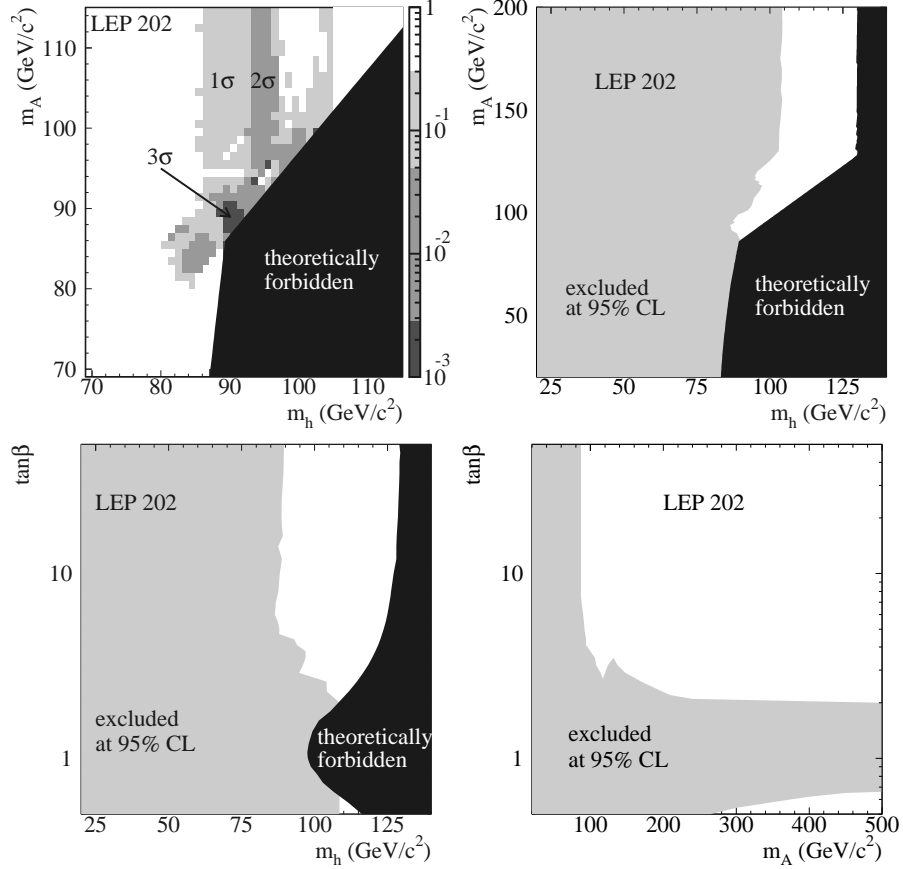

Figure 5: MSSM parameter scan results in direct comparison with Fig. 4.

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4 Charged Higgs Bosons

The search for charged Higgs bosons is performed in the framework of the general extension of the SM with two Higgs boson doublets. The combined results from the four LEP experiments for the reactions $e^+e^- \to H^+H^- \to c\bar{s}\bar{c}s$, $cs\tau\nu$, and $\tau^+\nu\tau^-\bar{\nu}$ are presented in Fig. 6, resulting in the limit of 78.6 GeV/c^2 at 95% CL, which is valid for any branching ratio Br($H^+ \to \tau^+\nu$).
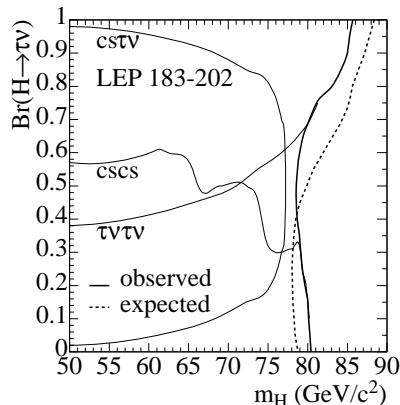

Figure 6: The 95% CL bounds on $m_{H^\pm}$ as a function of the branching ratio Br($H^+ \to \tau^+\nu$), combining the data collected by the four LEP experiments at energies from 183 to 202 GeV. The expected median exclusion limits are indicated by the dashed line and the observed limits by the heavy full line. The light full lines show the observed limits channel by channel.

5 Conclusions

The combination of the 1999 data from the four LEP experiments resulted in a large increase for the sensitivity of Higgs bosons; however, no indication of a signal has been found. Stringent mass limits are set for the SM Higgs boson, the neutral Higgs bosons of the MSSM, and charged Higgs bosons. Owing to the large luminosity of the combined data, a general scan of the MSSM parameters excludes neutral Higgs bosons below 86 GeV and the range $0.7 < \tan\beta < 1.8$.

Acknowledgments

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